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Research Article

THE VARIABILITY OF SELECTED FEATURES OF THE MORPHOLOGICAL STRUCTURE OF SCOTS PINE INTRODUCED ON A RECLAIMED WASTE DUMP OF A FORMER SULFUR MINE IN PIASECZNO

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ABSTRACT

This paper presents the results of studies on the variability of selected features of the morphological structure of Scots pine trees, introduced on the post-mining lands in Piaseczno reclaimed for forestry. The field research was conducted in 2014 in the north-western part of a waste dump, on one-are circular sample plots. These plots were established in three groups, depending on the type of a substrate and the implemented reclamation treatments (1 – the Quaternary loose sands, 2 – mixed sediments of the Quaternary loose sands and the Tertiary Krakowiec clays, 3 – mixed sediments of the Quaternary loose sands and the Tertiary Krakowiec clays after an intensive preplant fertilization). The Scots pine trees introduced on the reclaimed dump displayed various crown structures and growth parameters. The longest and the widest crowns were recorded for the pine trees growing on mixed sediments of sands and clays, whereas the trees growing on loose sands had the smallest diameters at breast height.

Keywords: forest reclamation, post-mining areas, diameter at breast height, tree height, crown length and width

INTRODUCTION

Scots pine (*Pinus sylvestris* L.) is a very important forest-forming species in Europe, due to which it has attracted many researchers focused on the recognition of its diversity, including the genetic variability [Soranzo et al. 2000, Boratyńska and Bobowicz 2001, Prus-Głowacki et al. 2003, Naydenov et al. 2007]. This is a predominant species in Polish forests, growing on ca. 60% of the total area of forest lands in Poland [GUS Leśnictwo 2015]. A characteristic trait of the Scots pine is its high ecological tolerance, thanks to which it can easily grow under diversified habitat conditions [Obmiński 1970]. Due to this, it is often planted on post-mining lands subject to the forest reclamation [Baumann et al. 2006, Pietrzykowski et al. 2014]. In Poland the area of post-mining lands, reclaimed and managed as commercial forests, amounts to 60% of all lands restored [Krzaklewski 2001, Kasztelewicz and Ptak 2011]. In great majority, the substrates encountered at these sites are formed by a mixture of various sediments (sands, clays, loams or silts). The reclamation activity, conducted in Poland since 1960's [Krzaklewski 2001], allows us to assess the measurable adaptive capabilities of forest tree species, and how they adjust to habitat conditions occurring in post-mining areas. Features of the morphological structure of pine trees growing on forest lands have been recognized considerably well [Obmiński 1970; Jaworski 2011]. However, there is still little data on how these features change in trees living on the reclaimed sites.

Thus, this paper aimed to determine the mean values and the range of variability of the selected morphological features of Scots pine trees, introduced on the reclaimed external waste dump of the "Piaseczno" Sulfur Mine, depending on the type of soil, on which they grew, and the reclamation treatments employed.

RESEARCH MATERIALS AND METHODS

The research was carried out on the external waste dump of the "Piaseczno" Sulfur Mine, the formation of which started in 1959. The post-mining site under analysis is located on the left-bank floodplain of the Vistula river, near Tarnobrzeg in the Sandomierz Basin, within the mesoregion of the Vistula Lowland [Zielony and Kliczkowska 2012]. The waste dump was mainly built of rocks of the sulfur mine overburden, which consisted mainly of the Tertiary and Quaternary sands, and the Tertiary Krakowiec clays [Pawłowski et al. 1965]. During exploitation of sulfur deposits no selective management of the overburden was performed. Due to this, some parts of the waste dump were built of sandy sediments, others consisted of clays, and certain parts of the site in question composed of the above-mentioned sediments mixed. The waste dump was ultimately shaped in a form of a frustum of a cone, and took up an area of ca. 120 ha [Węgorek 2003]. Woody plants were introduced on the dump in the years 1967-1969. The plantations established on the external waste dump were characterized by a diversified species composition, the aim of which was to grow mixed forest stands. The structure of regeneration was dominated by an alder (introduced as a transitional species), and a Scots pine. Apart from these, there were also other tree species, planted as a group mixture, such as: an European larch, red oak and a durmast oak [Ziemnicki et al. 1980].

The field research was conducted in spring and fall of 2014, in the north-western part of the waste dump. The investigations covered one-are, circular sample plots located in Scots pine stands, aged over 40 years. The selection of certain locations for establishing sample plots was preceded by an analysis of the reclamation-related documentation [Ziemnicki et al. 1980], and the habitat and soil conditions, the determination of which was based on the soil survey. In total, 17 sample plots were set up, located on various substrates, such as:

- the Quaternary loose sands (LS) – 5 plots;
- mixed sediments of the Quaternary sands and the Tertiary Krakowiec clays (SC) – 5 plots;
- mixed sediments of the Quaternary sands and the Tertiary clays after an intensive preplant fertilization (SCF) (200 kg of urea, 200 kg of potassium chloride [40%] and 320 kg of superphosphate per 1 ha) [Ziemnicki et al. 1980] – 7 plots.

On every sample plot an assessment of every tree in terms of its biosocial position was drawn according to Kraft's classification [Erteld and Hengst 1966], and then the following parameters were measured:

- a tree height was measured by means of the Suunto altimeter with an accuracy of 0.1 m,
- a diameter at breast height (DBH) of all trees was measured by means of calipers with an accuracy of 0.01 cm; the measurements were taken twice, at a height of 1.3 m of the tree trunk, in perpendicular directions, and then a mean value of these two measurements was calculated,

Moreover, on every sample plot four trees counted to the II Kraft's class were selected, for which the following measurements were taken:

- a crown length, i.e. a distance between the tree top and the lowest living branches forming an exact crown, was measured by means of the Suunto altimeter with an accuracy of 0.1 m; then, a relative crown length was computed as a percent ratio between the crown length and the tree height,
- a crown projection area measured from a tree trunk in four directions: north (N), south (S), east (E) and west (W), by means of a measuring tape with an accuracy of 10 cm,
- a bark thickness measured on trunks at a height of 1.3 m (DBH) in four directions (N, S, E and W), by means of a bark gauge with an accuracy of 1 mm,

The field research results were compared, and then mean values and coefficients of variation were computed. Statistical analyses employed a set of procedures listed below [Stanisz 1998, StatSoft, Inc. 2011]. The consistency of empirical distributions with the normal distribution was evaluated using the Shapiro-Wilk test. The homogeneity of variance within the groups under analysis was estimated with the use of Levene's test. The significance of differences between the mean values calculated for multiple samples was verified by means of the variance analysis, whereas the identification of the group responsible for rejecting the null hypothesis, relating to the equality of mean values, was performed with the use of Scheffe's test. With regard to the data that failed to meet the assumptions of the parametric test, the Kruskal-Wallis test and the multiple comparison test were employed respectively. For testing the significance of differences between two populations the Mann-Whitney U test was used The significance level assumed for all the above-mentioned statistical analyses was $p \leq 0.05$.

RESULTS

Diameters at breast height and heights of 135 pine trees were measured; they were also classified to the respective Kraft's class. Taking into account the entire research material, on every one-are sample plot there were nearly eight trees (7.9), on average. The highest mean quantity (9.8) was recorded on the LS substrate, while the mean quantities of trees on the other two substrates (SC and SCF) were lower, amounting to 7.2 and 7.1, respectively. However, no significant differences between the three types of a substrate under analysis, in terms of the number of trees growing on particular sample plots, were revealed (the Kruskal-Wallis test: $p = 0.1100$).

As presented in Table 1, almost 65% of all the individuals under investigation were counted to the II Kraft's class, i.e. dominant trees, while ca. one-fourth of trees were identified as low co-dominant (III Kraft's class). There were also few individuals representing the I and the IV Kraft's classes. The least diversified in terms of a biosocial structure were plots located on the SCF substrate, where more than three-fourths of the total number of trees were counted to the dominant class, and 20% to the co-dominant. A similar structure was encountered on plots on the SC substrate, while a greater diversification was observed on plots on the LS substrate, where nearly half of the total number of trees were counted to the II Kraft's class, and 36% to the III class. On the latter, the share of trees in the marginal classes was also the highest (Table 1). According to the methodological assumptions, detailed measurements of the morphological structure of trees covered the dominant individuals, i.e. those classified to the most numerous II Kraft's class.

The mean values of diameters at breast height and heights for all the trees under analysis amounted to 21.5 cm and 16.7 m, respectively (Table 1). The variability in mean values of these parameters computed within the groups of trees growing on the above-mentioned three types of a substrate was moderate, with coefficients of variation (V) reaching 10.6% and 8.1%, respectively. A slightly greater diversity was recorded for the mean values calculated for sample plots situated on the same substrate, either SC or SCF, while with regard to the LS substrate, the mean values were less diversified. The investigations revealed that the pine trees growing on the SC and SCF substrates had significantly larger diameters when compared with those on the LS substrate (Table 2). The mean values of this parameter amounted to 23.1 cm, 22.5 cm and 18.9 cm, respectively. The thickest pine tree was encountered on the sample plot no. 14, established on the SCF substrate; its diameter at breast height reached 33.7 cm. Whereas, the thinnest tree, with a diameter of 12.2 cm, grew on the plot no. 7, on the LS substrate.

Pine trees growing on the SCF substrate were significantly higher than those on the LS and SC substrates (Table 3). The differences in the mean heights amounted to 2.4 m in the first case, while in the second case it was slightly smaller, and took a value of 2.3 m (Table 1). The highest pine tree had a height of 21 m and was also the thickest individual measured (sample plot no. 14, on the SCF substrate). The smallest pine tree had a height of 11.5 m and grew on the SC substrate (sample plot no. 1).

According to the methodological assumptions, a detailed analysis of other features of the morphological structure of trees was performed based on measurements of pine trees representing the II Kraft's class, which constituted nearly 65% of all the individuals under investigation (Figure 1). The mean crown length for all those trees amounted to 6.3 m, while the relative crown length was 36.7%. The variability in both of the above-mentioned parameters, in respect to their mean values computed for the substrate-related groups of trees, was similar, and the coefficient of variance reached the level of 12.7% in the first case, whereas in the second case it was 15.4%. The smallest diversification in the both values of crown length was recorded for trees growing on the LS substrate, for which the coefficients of variance between the mean values obtained for particular sample plots were as follows: 14.2% for the crown length, and 13.8% for the relative crown length. A slightly greater variability in this parameter was revealed for pine trees on the SC substrate, where the aforementioned coefficients of variance reached 19.3% and 14.3%,

Table 1. Comparison between the number of trees within the particular Kraft's classes and basic statistics of features of the morphological structure of pine trees under analysis

Sample plot no.	Number of trees					Type of statistics	DBH [cm]	H [m]	CL [m]	RCL [%]	CW [m]	BT [cm]
	Kraft's class				Total							
	I	II	III	IV								
	[indv] [%]	[indv] [%]	[indv] [%]	[indv] [%]								
LOOSE SANDS (LS)												
3	**1**	**6**	**5**	**0**	**12**	**mean**	**19.2**	**14.3**	**5.6**	**36.4**	**3.2**	**1.3**
	8.3	50.0	41.7	0.0		V [%]	13.0	11.8	15.2	16.9	5.4	9.9
7	**0**	**5**	**5**	**1**	**11**	**mean**	**18.0**	**15.4**	**4.8**	**28.9**	**3.0**	**1.2**
	0.0	45.5	45.5	9.1		V [%]	14.5	6.5	27.5	29.4	6.5	2.9
8	**1**	**4**	**2**	**0**	**7**	**mean**	**17.9**	**15.8**	**6.2**	**37.6**	**2.7**	**1.2**
	14.3	57.1	28.6	0.0		V [%]	16.6	9.5	29.8	27.3	13.3	13.5
9	**1**	**4**	**3**	**2**	**10**	**mean**	**18.1**	**16.3**	**4.8**	**27.7**	**2.4**	**1.4**
	10	40	30	20		V [%]	11.6	7.8	27.9	26.4	17.4	10.3
10	**2**	**4**	**3**	**0**	**9**	**mean**	**21.2**	**17.7**	**6.4**	**35.5**	**2.2**	**1.5**
	22.2	44.4	33.3	0.0		V [%]	15.7	10.4	12.8	14.5	15.9	8.3
Total	**5**	**23**	**18**	**3**	**49**	**mean**	**18.9**	**15.9**	**5.6**	**33.2**	**2.7**	**1.3**
	10.2	46.9	36.7	6.1		V [%]	7.3	7.9	14.2	13.8	15.3	9.7
SANDS AND CLAYS (SC)												
1	**0**	**7**	**2**	**1**	**10**	**mean**	**22.9**	**14.9**	**7.8**	**47.7**	**4.0**	**1.4**
	0.0	70.0	20.0	10.0		V [%]	13.1	13.2	23.5	23.4	9.6	15.5
2	**0**	**7**	**1**	**0**	**8**	**mean**	**19.1**	**15.6**	**5.4**	**34.0**	**2.3**	**1.3**
	0.0	87.5	12.5	0.0		V [%]	8.0	6.1	15.6	17.6	17.9	9.0
4	**1**	**4**	**1**	**0**	**6**	**mean**	**27.1**	**17.5**	**7.9**	**44.5**	**2.8**	**1.6**
	16.7	66.7	16.7	0.0		V [%]	15.1	11.1	13.1	12.6	25.1	14.0
5	**0**	**4**	**2**	**0**	**6**	**mean**	**18.8**	**14.6**	**6.0**	**40.3**	**2.8**	**1.3**
	0.0	66.7	33.3	0.0		V [%]	10.7	3.3	14.0	12.2	28.6	6.6
6	**1**	**4**	**1**	**0**	**6**	**mean**	**27.5**	**17.5**	**8.7**	**49.3**	**3.8**	**1.6**
	16.7	66.7	16.7	0.0		V [%]	9.2	6.9	13.1	13.9	21.8	21.7
Total	**2**	**26**	**7**	**1**	**36**	**mean**	**23.1**	**16.0**	**7.2**	**43.1**	**3.1**	**1.4**
	5.6	72.2	19.4	2.8		V [%]	18.2	8.7	19.3	14.3	22.3	12.3
SANDS AND CLAYS FERTILIZED (SCF)												
11	**0**	**8**	**3**	**1**	**12**	**mean**	**19.5**	**18.3**	**4.4**	**23.1**	**2.5**	**1.5**
	0.0	66.7	25.0	8.3		V [%]	16.8	6.5	9.6	8.2	10.7	12.8
12	**0**	**7**	**1**	**0**	**8**	**mean**	**21.2**	**19.1**	**8.4**	**42.5**	**2.8**	**1.6**
	0.0	87.5	12.5	0.0		V [%]	10.7	5.1	5.7	6.7	13.3	7.1
13	**0**	**4**	**1**	**0**	**5**	**mean**	**24.9**	**19.1**	**6.1**	**30.8**	**3.2**	**1.7**
	0.0	80.0	20.0	0.0		V [%]	19.9	7.8	7.0	5.2	23.1	14.8
14	**1**	**4**	**0**	**0**	**5**	**mean**	**27.7**	**19.8**	**6.8**	**35.1**	**2.7**	**1.6**
	20.0	80.0	0.0	0.0		V [%]	13.3	4.0	8.1	8.8	10.4	13.1
15	**0**	**4**	**1**	**0**	**5**	**mean**	**22.3**	**18.1**	**6.3**	**33.3**	**2.6**	**1.7**
	0.0	80.0	20.0	0.0		V [%]	11.7	10.1	24.9	26.2	25.5	6.1
16	**0**	**6**	**3**	**0**	**9**	**mean**	**22.0**	**18.1**	**4.9**	**26.2**	**2.2**	**1.9**
	0.0	66.7	33.3	0.0		V [%]	10.5	7.5	15.7	12.6	10.0	27.6
17	**0**	**5**	**1**	**0**	**6**	**mean**	**19.9**	**15.8**	**7.1**	**44.3**	**3.3**	**1.8**
	0.0	83.3	16.7	0.0		V [%]	13.0	4.9	16.6	17.8	12.2	15.3
Total	**1**	**38**	**10**	**1**	**50**	**mean**	**22.5**	**18.3**	**6.3**	**33.6**	**2.7**	**1.7**
	2.0	76.0	20.0	2.0		V [%]	12.9	6.9	21.2	23.3	13.5	7.8
Total	**8**	**87**	**35**	**5**	**135**	**mean**	**21.5**	**16.7**	**6.3**	**36.7**	**2.9**	**1.5**
	5.9	64.4	25.9	3.7		V [%]	10.6	8.1	12.7	15.4	8.3	12.4

DBH – diameter at breast height, H – height, CL – crown length, RCL – relative crown length, CW – crown width, BT – bark thickness, V - coefficient of variance.

Table 2. Sheffe's test "p" values; variable: diameter at breast height (variance analysis: p=0.0000)

Substrate type	LS	SC
SC	0.0000	–
SCF	0.0004	0.5243

Table 3. Multiple comparison test "p" values; variable: height (Kruskal-Wallis test: p=0.0000)

Substrate type	LS	SC
SC	1.0000	–
SCF	0.0000	0.0000

Table 4. Sheffe's test "p" values; variable: crown length (variance analysis: p= 0.0049)

Substrate type	LS	SC
SC	0.0050	–
SCF	0.2502	0.1484

Table 5. Sheffe's test "p" values; variable: relative crown length (variance analysis: p= 0.0003)

Substrate type	LS	SC
SC	0.0018	–
SCF	0.9885	0.0012

Table 6. Multiple comparison test "p" values; variable: bark thickness (Kruskal-Wallis test: p=0.0000)

Substrate type	LS	SC
SC	0.4536	–
SCF	0.0000	0.0052

respectively. The most varied were the crown lengths measured for trees growing on the SCF substrate, where the coefficients took values of 21.2% and 23.3%, respectively. A tree with the longest crown, measuring 10.2 m, grew on the SC substrate (sample plot no. 1); it also had the greatest relative crown length. The smallest values of the crown length and the relative crown length were recorded for a pine tree on the LS substrate (sample plot no. 7), and they amounted to 3.0 m and 17.6%, respectively. The authors established that the pine trees growing on the SC substrate had significantly greater crown lengths and relative crown lengths when compared with those on the LS substrate, and significantly greater relative crown lengths than those of pine trees on the SCF substrate (Tables 4 and 5).

The mean crown width computed for all the pine trees under analysis amounted to 2.9 m, while the coefficient of variance between the mean values obtained for the three types of a substrate reached the level of 8.3%. Both trees with the widest (5.0 m) and the narrowest (1.7 m) crown grew on the SC substrate (sample plots nos. 6 and 2, respectively). This parameter was the least varied in the group of trees on the SCF substrate, where the coefficient of variance within the particular sample plots took a value of 13.5%. A similar variability was recorded for trees growing on the LS substrate (V = 15.3%), whereas the most diversified crown width revealed pine trees on the SC substrate (V = 22.3%). Although the crown width of pine trees on the SC substrate was indeed by 0.4 m, on average, greater than that of trees on the LS and SCF substrates, the variance analysis did not prove any statistical significance of these differences (p = 0.0595).

The mean bark thickness measured for all the investigated pine trees amounted to 1.5 cm, while the coefficient of variance between the mean values calculated for the particular substrate types reached the level of 12.4%. The thickest bark, measuring 2.7 cm, was recorded for a pine tree growing on the SCF substrate (sample plot no. 16), whereas the thinnest bark (1.0 cm) covered a tree trunk on the LS substrate (sample plot no. 8). The greatest variability in this parameter was revealed on the SC substrate, where the coefficient of variance between the mean values obtained for particular sample plots amounted to 12.6%. In this respect, slightly less varied were the trees growing on the LS substrate (V = 9.7%), while the least diversified was the bark thickness of pine trees on the SCF substrate (V = 7.8%). The analysis proved that the bark thickness of pine trees growing on the SCF substrate was significantly greater when compared with those on the LS and SC substrates (Table 6). The differences between the mean values amounted to 0.7 cm and 0.4 cm, respectively.

No statistically significant differences between the respective parameters measured in the N-S and the E-W directions were revealed, which concerns the diameter at breast height (Mann-Whitney U test: p = 0.6173), crown width (Mann-Whitney U test: p = 0.2322), and the double bark thickness (Mann-Whitney U test: p = 1.0000). Moreover, the crown projection area and the bark thickness did not differ significantly depending on the measurement direction; the "p" values of the Kruskal-Wallis tests amounted to 0.1068 and 0.8142, respectively.

DISCUSSION

The effects of forest reclamation can be reliably evaluated only within the long-term time intervals. In Poland, the reclamation activity has been performed, in an organized manner, for over 60 years, and now it offers us an opportunity to investigate the conditions of afforestation introduced on the lands reclaimed for forestry in stands advancing from I to II, and from II to III age classes [Krzaklewski 2001]. Among the Polish researchers who have addressed the issue of variability of morphological features of a Scots pine growing on post-mining lands reclaimed for forestry, in habitats of various fertility, the following should be named: Pająk et al. [2004], Ochał et al. [2010], Pająk and Krzaklewski [2010], and Pająk et al. [2011]. The aforementioned authors indicated that both, the height and the diameter at breast height of pine trees within the I and II age classes, growing on less fertile sediments of post-mining sites, took clearly lower values than those of trees living on more fertile soils. This was also confirmed by the results of the studies presented in this paper.

As a result of the analyses performed, it was established that dimensions of trees (their diameters at breast height and heights) were indeed the smallest when they grew on soils composed of loose sands. However, Torbert et al. [1990], who investigated pine trees *Pinus x rigitaeda* growing on reclaimed post-mining lands in Virginia (USA), reported an opposite dependence. Heights and diameters at breast height of trees living on infertile sands were the greatest, and as the content of silty admixture increased, the dimensions of trees decreased. On average, the differences in heights and diameters at breast height between trees growing on infertile sands and those living on silty sediments amounted to 1.91 m and 4.6 cm, respectively. The aforementioned authors explained this phenomenon with the fact that the sandy sediments resembled natural forest habitats more closely than the silty ones, and the pine trees preferred the former. In Estonia, similar studies were carried out by Kuznetsova et al. [2009], who compared the growth of a Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) planted on reclaimed post-mining lands, post-agricultural wastelands and forest areas. The investigations revealed that trees with the greatest dimensions were those growing on post-agricultural wastelands (with a height of 11.5 m and a diameter at breast height of 15.1 cm), followed by those on post-mining sites (with a height of 9.1 m and a diameter at breast height of 14.5 cm), while the smallest dimensions were recorded for trees living in forests (with a height of 5.9 m and a diameter at breast height of 8.7 cm).

Similar results were obtained in the course of another studies conducted in Estonia, this time covering Scots pine trees, which were higher and had greater diameters at breast height when growing on reclaimed post-mining sites than those on forest soils [Kuznetsova et al. 2010]. The mean heights and diameters at breast height of trees on the reclaimed lands amounted to 8.7 m and 10.5 cm, while in forest habitats they took values of 4.9 m and 7.3 cm, respectively. Moreover, the investigations revealed that the annual growth in height of pine trees living on the reclaimed lands was greater, ranging from 36 cm to 45 cm, when compared with that of trees in forest habitats, where it was 23 cm. The above-quoted authors explained that greater dimensions of pine trees on post-mining lands were due to a higher content of potassium (K) and calcium (Ca) in soil, which considerably induced a better growth of trees in this region.

Conclusions consistent with these presented here were published by Jaworski [2011], who stated that Scots pine trees growing on infertile soils composed of loose sands were characterized by considerably smaller dimensions than those living on sediments formed by clays, loess and silty sands.

The authors of this paper have not found any data relating to the variability in parameters of crowns of pine trees growing on post-mining lands in Poland. Skrzyszewski [2001], having investigated pine trees in mature and overmature forest stands in the lowlands, sub-mountain regions and in the mountains, reported the following values for mean crown lengths: 10.3 m, 9.9 m and 10.2 m, and for relative crown lengths: 37.4%, 33.4% and 36.1%, respectively. Whereas, Jelonek et al. [2009], who studied 60- and 70-year-old pine trees from northern Poland, established that a mean crown length of trees growing in fresh coniferous forest amounted to 7.3 m, while in fresh mixed coniferous forest it was 7.2 m. The latter authors also reported a mean crown length computed for pine trees representing the II Kraft's class, which took a value of 7.5 m. In the course of the studies presented here, lower mean values of crown lengths were obtained, which might have been due to clearly younger age of the pine trees under analysis than those investigated by Skrzyszewski [2001] and Jelonek et al. [2009]. Nevertheless, with regard to the mean values of relative crown length, the data presented here was similar to that quoted by Skrzyszewski [2001], and amounted to 33% for pine trees growing on the LS and SCF substrates. A significantly higher mean value of this parameter was recorded for trees on the SC substrate (43.1%), which indicated that the process of self-cleaning of trunks from branches was slower in this case. Thus, such trees were expected to produce trunks of slightly worse technical quality in the future.

The mean values of crown widths reported in this paper, oscillating around 3 m, were lower than those given by Jelonek et al. [2009] for 60- and 70-year-old pine trees, which ranged between 3.7 m and 4.0 m, depending on the habitat type. They were also lower when compared with those quoted by Skrzyszewski [2001] for pine trees aged over 80 years, ranging from 5.0 m to 5.8 m. Taking into account the above-quoted mean values and the age of trees, the crown widths of pine trees growing on the waste dump discussed here are expected to increase in the future.

The statistical analyses performed in these studies revealed that the pine trees growing on the SCF substrate had significantly thicker bark than that of trees on the LS and SC substrates. Therefore, in future planning of timber harvesting on a waste dump, where a preplant fertilization has been performed, a slightly greater weight of raw wood should be assumed, when compared with that of timber obtained from sites on the other two types of a substrate. This is due to the fact that the weight of roundwood to be transported is computed based on the volume of raw wood without bark, which makes the bark thickness irrelevant in such calculations.

CONCLUSIONS

1. The pine stands under analysis, situated on the waste dump of the former Sulfur Mine in Piaseczno, displayed a biosocial structure resembling that of a commercial pine stand growing in fresh mixed coniferous forest.
2. The pine trees planted on mixed sediments of sands and clays fertilized (SCF) were significantly higher than those growing on sandy soils (LS), and mixed sediments of sands and clays (SC).
3. The pine stands growing on sandy sediments (LS) of the waste dump were characterized by significantly smaller diameters at breast height when compared with those on mixed sediments of sands and clays (SC), and mixed sediments of sands and clays fertilized at the beginning of the reclamation process (SCF).
4. The pine trees introduced on the waste dump reclaimed for forestry displayed varied structures of crowns. The longest and the widest crowns were reported for pine trees growing on mixed sediments of sands and clays (SC), and they were significantly larger than those of pine trees planted on sandy sediments (LS).
5. Bark of pine trees growing on mixed sediments of sands and clays fertilized during the reclamation process (SCF) was significantly thicker when compared with that of trees planted on sandy soils (LS) and mixed sediments of sands and clays (SC).
6. Taking into consideration the mean values of the diameter at breast height and the bark thickness computed for pine trees growing on mixed sediments of sands and clays (SC), as well as sands and clays fertilized (SCF), the preparation of soil by means of preplant fertilization, preceding an introduction of pine trees on the substratum composed of sands and clays, seems useless and unjustified.

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